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**APPLICATION  
FOR  
UNITED STATES  
LETTERS PATENT**

**APPLICANT'S: IPPEI FUJIMOTO, ET AL.**

**FOR: ELECTRODE FOR p-TYPE GROUP III  
NITRIDE COMPOUND SEMICONDUCTOR  
AND METHOD FOR PRODUCING THE  
SAME**

**DOCKET NO.: T36-159874M/KOH**

ELECTRODE FOR p-TYPE GROUP III NITRIDE COMPOUND SEMICONDUCTOR  
AND MEHOD FOR PRODUCING THE SAME

The present application is based on Japanese Patent  
5 Application No. 2002-318469, which is incorporated herein by  
reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

10 The present invention relates to an electrode low in  
contact resistance to a p-type Group III nitride compound  
semiconductor. It also relates to a method for producing an  
electrode with reduced contact resistance. Incidentally, the  
concept "Group III nitride compound semiconductor" includes  
15 semiconductors represented by the general formula:  $\text{Al}_x\text{Ga}_y\text{In}_{1-x-y}\text{N}$   
( $0 \leq x \leq 1$ ,  $0 \leq y \leq 1$ ,  $0 \leq x+y \leq 1$ ) which includes binary compounds such  
as AlN, GaN and InN, ternary compounds such as  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ,  $\text{Al}_x\text{In}_{1-x}\text{N}$   
and  $\text{Ga}_x\text{In}_{1-x}\text{N}$  ( $0 < x < 1$  each), and quaternary compounds such as  
 $\text{Al}_x\text{Ga}_y\text{In}_{1-x-y}\text{N}$  ( $0 < x < 1$ ,  $0 < y < 1$ ,  $0 < x+y < 1$ ).

20 2. Description of the Related Art

When, for example, Group III nitride compound  
semiconductors are applied to light-emitting devices, the Group  
III nitride compound semiconductors are direct transition type  
semiconductors having a wide emission spectrum range of from  
25 ultraviolet to red. The Group III nitride compound

semiconductors are applied to light-emitting diodes (LEDs), laser diodes (LDs) and so on. Because each Group III nitride compound semiconductor has a wide band gap, there is expectation that devices using Group III nitride compound semiconductors will operate more stably at a high temperature than devices using other semiconductors. For this reason, application of Group III nitride compound semiconductors to transistors such as FETs has been developed actively. In addition, because each Group III nitride compound semiconductor contains no arsenic (As) as a main component, there is expectation that Group III nitride compound semiconductors will be developed to various semiconductor devices for general purposes from an environmental aspect.

In a compound semiconductor, it is usually impossible to obtain an ohmic contact when metal is formed simply on a surface of the semiconductor. Therefore, after a metal film is formed on the compound semiconductor, alloying is made by a heat treatment (sintering) to diffuse metal into the semiconductor to thereby obtain an ohmic contact. Particularly in a p-type Group III nitride compound semiconductor, even in the case where resistance is reduced by a heat treatment such as electron beam irradiation, the resistivity of the p-type Group III nitride compound semiconductor is still higher than the resistivity of an n-type Group III nitride compound semiconductor. Accordingly, for example, in a light-emitting

device, there is little lateral spread of a current in the p-type layer, so that light is emitted only just under the electrode. Therefore, a current diffusing electrode formed in such a manner that films of nickel (Ni) and gold (Au) each having a thickness  
5 of the order of tens of nm are laminated and heat-treated has been proposed as an electrode having both light-transmitting characteristic and ohmic characteristic (e.g., see Patent Document 1). Even in this case, when, for example, the electrode for p-type gallium nitride (GaN) is composed of Ni and Au, the  
10 contact resistivity  $\rho_c$  of the electrode is high to be  $7 \times 10^{-3}$  /cm<sup>2</sup> in the present circumstances.

Incidentally, as described above, in the compound semiconductor, it is impossible to obtain an ohmic junction when metal is formed simply on the semiconductor surface, so  
15 that simple deposition of metal generally brings Schottky characteristic. It is conceived that this is because a Schottky barrier  $\Phi_B$  ( $\Phi_B = (X + E_g) - \Phi_m$ ) to movement of a carrier is formed in a boundary between the compound semiconductor and the metal as shown in Fig. 1 (e.g., see Non-Patent Document  
20 1).

On the other hand, oxide and other deposits are present on a surface of the compound semiconductor, so that these deposits cause increase in contact resistance between the compound semiconductor and the metal. To solve this problem,  
25 for example, a chemical treatment and a sputtering treatment

using an inert gas have been proposed (e.g., see Patent Document 2).

[Patent Document 1]

Unexamined Japanese Patent Publication No. Hei-6-314822

5 [Patent Document 2]

Unexamined Japanese Patent Publication No. Hei-8-264478

[Non-Patent Document 1]

Tetsuji Imai et al., "Compound Semiconductor Devices [II]", Kogyo Chosakai Publishing Co., Ltd., pp.73-76

10 It is said that reduction in the Schottky barrier  $\Phi_B$  or the width of a depletion layer formed in the boundary between the p-type semiconductor and the metal is indispensable for reduction in contact resistance between the compound semiconductor and the metal and further leads to greater  
15 reduction in contact resistivity at the time of formation of an ohmic junction based on a heat treatment after that. In the present circumstances, essential issues such as the substance of the compound semiconductor/metal boundary, the relation with the metal boundary structure, and so on, are not  
20 yet exactly known. It is an urgent necessity to settle the essential issues.

#### SUMMARY OF THE INVENTION

The present inventors have made eager investigation into  
25 the essential issues such as the substance of the compound

semiconductor (especially, Group III nitride compound semiconductor)/metal boundary and the relation with the metal boundary structure and have made an examination of orientation of a metal film formed on the semiconductor, height of a Schottky  
5 barrier and electric characteristic between the compound semiconductor and the metal while paying attention to the orientation of the metal film. As a result, the invention is accomplished. That is, the invention is developed to solve the problem and an object of the invention is to provide an  
10 electrode low in contact resistance to p-type Group III nitride compound semiconductor. Another object of the invention is to provide a method for producing an electrode having reduced contact resistance.

To solve the problem, the invention provides an electrode  
15 for p-type Group III nitride compound semiconductor, including a film at least containing polycrystalline metal. Preferably, the polycrystalline metal has such a fiber structure that crystal planes of crystal grains are oriented. This is because, when the polycrystalline metal has a fiber structure, crystal grain  
20 boundary density decreases so that the quantity of defects in the metal/semiconductor boundary decreases. Preferably, the polycrystalline metal has large crystal grains. As a method to achieve these matters, according to the invention, there is provided a method of producing an electrode for p-type Group  
25 III nitride compound semiconductor, including the step of

forming a film at least containing polycrystalline metal on a p-type Group III nitride compound semiconductor in the condition that a semiconductor device having the p-type Group III nitride compound semiconductor is heated. According to this method, the metal film formed on the p-type Group III nitride compound semiconductor can contain the crystal having such a fiber structure that crystal planes of crystal grains are oriented. As the percentage occupied by such a crystal with a fiber structure increases, the orientation force of the metal film increases. The polycrystal in the metal film has such a fiber structure that crystal faces with closed packed planes are oriented. As a result, the height of the Schottky barrier between the compound semiconductor (especially, Group III nitride compound semiconductor) and the metal can be reduced by the strong orientation force of the metal, so that the value of contact resistance in the boundary between the p-type Group III nitride compound semiconductor and the metal can be reduced greatly.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 shows a current transporting mechanism in a metal/semiconductor boundary;

Fig. 2 shows a Marlow-Das type photolithography pattern for evaluation;

Fig. 3 is an I-V characteristic graph in the case of Pt;

Fig. 4 is an I-V characteristic graph in the case of Ni;

and

Fig. 5 is a graph showing the relation between (111) peak

5 intensity and value of contact resistance  $R_0$  of each metal film.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention will be described below on the basis of a specific embodiment thereof. A Marlow-Das type pattern  
10 (shaped like a circular ring with a center point) of  $\text{SiO}_2$  using photolithography was used as a metal electrode-forming pattern (Fig. 2). Here, the width  $d$  of the circular ring ( $\text{SiO}_2$ -forming portion) was set at 4, 8, 16 or 24  $\mu\text{m}$ . Gallium nitride (GaN) was used as a Group III nitride compound semiconductor. A 4  
15  $\mu\text{m}$ -thick layer of GaN was formed on a sapphire substrate using a face A as a principal surface with interposition of a low-temperature deposited buffer layer of aluminum nitride (AlN) by a metal organic chemical vapor deposition method (MOCVD method). A 0.5  $\mu\text{m}$ -thick layer of GaN doped with magnesium (Mg)  
20 to be formed as a p-type semiconductor was further formed on the GaN layer. The hole density of the p-type GaN layer was  $5 \times 10^{17} \text{ cm}^{-3}$ . Incidentally, the laminate composed of the sapphire substrate, AlN, GaN and p-type GaN is hereinafter referred to as "GaN" substrate. Evaluation was carried out  
25 by measurement of contact resistance  $R_0$  according to a current



(I)-voltage (V) method and structural analysis of the metal film according to XRD.

The GaN substrate having a p-type GaN surface cleaned with hydrochloric acid was placed in a chamber of an evaporation system. Then, on the GaN substrate heated to a temperature of 300°C, a 50 nm-thick metal layer was vapor-deposited by an electron beam vapor deposition method. The deposited metals were two kinds of metals, namely, platinum (Pt) and nickel (Ni). Incidentally, a sample formed with the same film thickness without heating the GaN substrate, that is, at room temperature (Comparative Example 1) and a sample heat-treated in a nitrogen (N<sub>2</sub>) atmosphere at 300°C for 30 minutes after that (Comparative Example 2) were prepared as Comparative Examples.

Tables 1 and 2 show results of the XRD measurement. Table 1 shows the case of Pt. Table 2 shows the case of Ni. Although spectra are not shown, no peak except (111) and (222) was observed in each of the cases of Pt and Ni. As is obvious from Tables 1 and 2, a large difference between this embodiment and Comparative Examples 1 and 2 appears in the intensity of (111) and the half-value width thereof. When, for example, Pt was vapor-deposited on the GaN substrate heated to a temperature of 300°C, the peak intensity of (111) and the half-value width thereof in this embodiment were 98534 and 0.4° respectively whereas the peak intensity of (111) and the half-value width thereof in Comparative Example 1 (room temperature formation)

were 3666 and  $2.5^{\circ}$  respectively and the peak intensity of (111) and the half-value width thereof in Comparative Example 2 (room temperature formation  $\rightarrow$   $300^{\circ}\text{C}$  heat treatment) were 32061 and  $2.2^{\circ}$  respectively. Even when a heat treatment at  $300^{\circ}\text{C}$  was

5 carried out in the same manner, a large difference appeared between the case where the heat treatment was carried during formation and the case where the heat treatment was carried after formation. The same result as in the case of Pt was obtained in the case of Ni. It is obvious that the (111)

10 orientation of crystal is intensified, that is, the percentage occupied by the crystal having such a fiber structure that crystal planes of crystal grains are oriented increases when the substrate is heated during formation. Incidentally, it is conceived that the (111) orientation is intensified in both

15 Pt and Ni because both Pt and Ni have a face-centered cubic structure (fcc). Incidentally, in the case of a body-centered cubic structure (bcc), it is guessed that the (100) orientation is intensified.

[TABLE 1]

	Pt(111) intensity	Pt(111) half-value width
This invention (substrate heating and vapor deposition)	98534	$0.4^{\circ}$
Comparative Example 1 (room temperature vapor deposition)	3666	$2.5^{\circ}$
Comparative Example 2 (room temperature vapor deposition $\rightarrow$ heating)	32061	$2.2^{\circ}$

[TABLE 2]

	Ni(111) intensity	Ni(111) half-value width
This invention (substrate heating and vapor deposition)	19998	0.5°
Comparative Example 1 (room temperature vapor deposition)	3135	1.7°
Comparative Example 2 (room temperature vapor deposition → heating)	5473	1.1°

Figs. 3 and 4 show results of the I-V characteristic. Fig. 3 shows the case of Pt. Fig. 4 shows the case of Ni. It is obvious from Figs. 3 and 4 that a large difference between this embodiment and Comparative Examples 1 and 2 appears in the value of contact resistance  $R_0$  calculated on the basis of the I-V characteristic. When, for example, Pt was vapor-deposited on the GaN substrate heated to a temperature of 300°C, the value of contact resistance  $R_0$  in this embodiment was  $3.8 \times 10^4 \Omega$  whereas the value of contact resistance  $R_0$  in Comparative Example 1 (room temperature formation) was  $8.5 \times 10^7 \Omega$  and the value of contact resistance  $R_0$  in Comparative Example 2 (room temperature formation → 300°C heat treatment) was  $3.3 \times 10^7 \Omega$ . When Ni was vapor-deposited on the GaN substrate heated to a temperature of 300°C, the value of contact resistance  $R_0$  in this embodiment was  $2.6 \times 10^4 \Omega$  whereas the value of contact resistance  $R_0$  in Comparative Example 1 (room temperature formation) was  $1.7 \times 10^6 \Omega$  and the value of contact resistance

$R_0$  in Comparative Example 2 (room temperature formation  $\rightarrow$  300°C heat treatment) was  $1.9 \times 10^7 \Omega$ . The result in the case of Ni was the same as that in the case of Pt. It is obvious that the value of contact resistance is reduced by two or three digits to improve electric characteristic remarkably when the substrate is heated during formation.

Fig. 5 shows the case where (111) peak intensity is taken as the horizontal axis and value of contact resistance  $R_0$  as the vertical axis on the basis of the aforementioned results.

Incidentally, Fig. 5 shows the fact that the percentage occupied by the crystal having such a fiber structure that crystal planes of crystal grains are oriented (grains with (111) fiber structure) in the film increases as the (111) intensity on the horizontal axis increases. It is obvious from Fig. 5 that the percentage occupied by such a crystal with a fiber structure in the metal film is correlated with the value of contact resistance  $R_0$ . It is proved that electric characteristic varies according to the degree of orientation of the metal, and that, particularly in a metal having a fcc structure, the value of contact resistance in the metal/GaN boundary decreases rapidly as the (111) orientation force increases.

Although GaN was used as the p-type Group III nitride compound semiconductor in this embodiment, similar results except variations in respective values were also obtained in the case where another p-type Group III nitride compound

semiconductor such as AlGa<sub>N</sub> or GaIn<sub>N</sub> was used. Although either Pt or Ni was used as the metal in this embodiment, it is guessed that similar results can be obtained in the case where a transition metal such as palladium (Pd), chromium (Cr) or iron (Fe) is used. In addition, the degree of large grains in the invention is preferably selected to be not smaller than the film thickness.

Although the substrate was heated to a temperature of 300°C during formation, the substrate temperature is preferably selected to be not lower than 200°C and not higher than lower one of the decomposition temperature of the semiconductor and the melting point of the metal. This is because a remarkable effect of the invention can be obtained when the substrate temperature is in the aforementioned range. Although a vapor deposition method was used as the metal film-forming method, there may be used another method such as a sputtering method, a laser annealing method as means for raising the temperature instantaneously to the melting point of the metal to be formed, or a plating method.

The invention is not limited to the description of the embodiment at all. Various modifications that can be easily conceived by those skilled in the art may be included in the invention without departing from the scope of claim for a patent.